

preliminary tremors in seconds. In the present case the calculated distance is 4445 kilometers (2762 miles), a result which, without corroborative data, must be regarded as very problematic.

The reasoning in this case is to this effect: Earthquakes in general are caused, it is believed, by more or less sudden breaks or slips or fractures in the crust of the earth. Yielding of a gradual sort may have been going on for a long time before, but when the final fracture comes the phenomenon we call an earthquake results, and elastic and quasi-elastic waves of both compression and distortion and of a highly complex character radiate from the origin in all directions. The purely elastic vibrations within the elastic limits of the strata, and hence of smaller amplitude, are undoubtedly transmitted at a higher linear velocity than the great surges which doubtless strain the earth materials far beyond the elastic limit and are soon dissipated. Hence, we should expect the earthquake record to begin with preliminary tremors and this is found to be the case, except in very rare instances. The absence of preliminary tremors in the case of the present earthquake as recorded at Victoria would indicate a nearby origin for the disturbance.

A study of the records of distant earthquakes shows a most marked difference in the velocity of propagation of different phases of the phenomena. From Omori's investigations, already referred to, the preliminary tremors are transmitted at an average velocity of 12.8 kilometers per second; whereas, the large waves of the principal portion of the earthquake travel at the slow rate of only 3.3 kilometers per second. The theory of the speed of propagation of vibrations would require that the elastic properties of the strata should exceed those of steel in order to give the observed high velocities of the preliminary tremors.

A satisfactory explanation of this apparent conflict with our knowledge of the elastic properties of bodies has not yet been offered. A theory has been advanced that the preliminary tremors make a short cut for the distant station by traveling through the earth rather than around it, but even in this case the transmitting medium must have a very high modulus of elasticity.

#### THE DISTRICTS OF THE DOMINION OF CANADA.

In answer to many inquiries the Editor submits the accompanying sketch map, kindly furnished by Prof. R. F. Stupart, showing the names and locations of recent subdivisions in the Northwest Provinces of Canada.

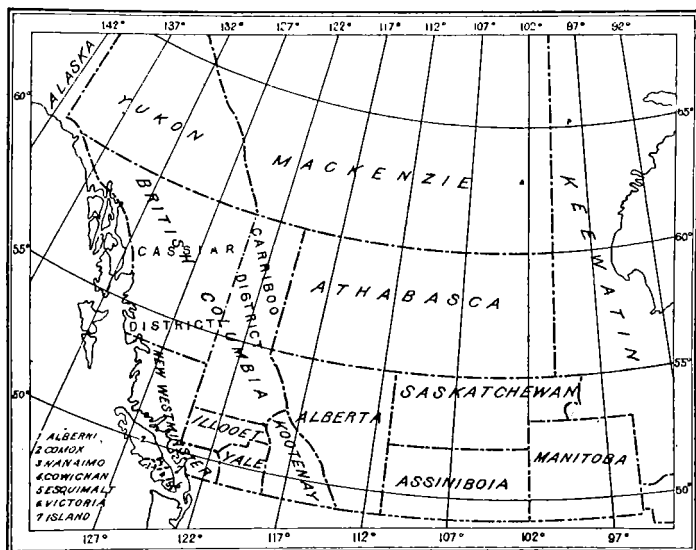


FIG. 1.—Districts of the Dominion of Canada.

#### THE SEMIDIURNAL TIDES IN THE NORTHERN PART OF THE INDIAN OCEAN.

By R. A. HARRIS, of the United States Coast and Geodetic Survey.

In this paper an attempt will be made to show by means of cotidal lines the average Greenwich lunar time of high water over the northern part of the Indian Ocean. Of course an unlimited number of sets of cotidal lines can be drawn which shall satisfy all reliable observations because the measurements of the tide have been confined to shores and islands. But unless one duly considers the causes and nature of the tide it is almost certain that such arbitrary lines will, when carried out far from land, represent an impossible state of affairs.

Before passing to the subject proper, it may be well here to call attention to the desirability of procuring more and better observations on many of the islands. Observations should also be made over shoals and, if possible, at places of greater depths.

It is the intention of the writer to cover the sea and all its principal arms with cotidal lines similar to those here shown in fig. 5. The maps showing such lines will probably also appear in an appendix to the United States Coast and Geodetic Survey Report for the year 1904. In view of this considerable delay, it is reasonable to suppose that the map accompanying this paper may by that time be modified somewhat in ways suggested by future observations and experience.

In fig. 5 Roman numerals denote the Greenwich lunar time of mean high water; when decreased by the east longitude of the place expressed in time they give its establishment in lunar hours. The Arabic numerals, generally scattered along the shores, denote the approximate mean range of tide in feet. Values given to tenths of a foot are based upon harmonic analyses; bracketed values indicate the range of the semi-diurnal part of the tide where the latter is chiefly diurnal.

The northern part of the Indian Ocean is chosen for study at this time because the origin of the tide is there more easily accounted for than in most other regions, and because the results of extensive observations made by the survey of India, by the Dutch, and by the British Admiralty are available.<sup>1</sup>

In Appendix No. 7, United States Coast and Geodetic Survey Report for 1900, an attempt is made to partially explain the principal ocean tides. A preliminary sketch of parts of the theory involved in this appendix may be found in the MONTHLY WEATHER REVIEW for March, 1900, and this sketch should be consulted if the full paper is not available.

The Indian Ocean north of the thirtieth degree of south latitude is, with one exception, but little influenced by the tides of other waters. The exception is due to the fact that there is a good rise and fall around southern Africa, and in Mozambique Channel, where the tide depends upon two systems of oscillations which are determined by boundaries largely outside of the region to be considered in this paper. These systems, styled south Atlantic and south Indian, are described in Chapter VII of the Appendix No. 7 above referred to. It may be noted here that observations indicate about 1.5 as the Greenwich lunar time of high water in Mozambique Channel, and that this is about the theoretical time of the tide, for it is a mean between XII or 0 and III; see fig. 1, which is taken from the chart of semidiurnal systems in the paper just referred to. Extending from Mozambique Channel to Baluchistan and India is a half-wave area whose time of tide, as will be noted later, is largely governed by the tide in the channel.

<sup>1</sup> Most of the data used in the construction of the accompanying map may be found in the British Admiralty Tide Tables; The United States Coast and Geodetic Survey Tide Tables; and Appendix No. 7, United States Coast and Geodetic Survey Report for 1900, sections 79-97 and figs. 25, 29.

## THE NORTH INDIAN SYSTEM.

This system consists of the canal-like whole-wave area extending from the northwestern coast of Australia to the coast of Somaliland and Arabia, and of a dependent fractional area, viz, the Bay of Bengal. Since the eastern part of the whole-wave area has much greater depth than the western, there are some advantages in regarding the whole strip as two half-wave areas.

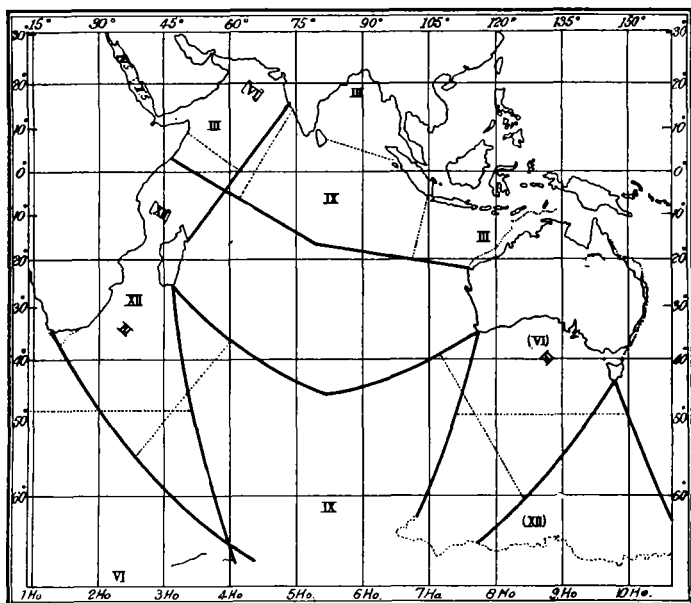


FIG. 1.

First of all it is required to ascertain the theoretical times of high water at the loops (i. e., ends and middle) of this strip by applying thereto arrows which denote the intensity and direction of the tidal forces at as many points as we find it necessary to take. In this instance the two points where the axis or central line crosses the two nodal lines will probably be sufficient. The positions of these points are about latitude  $12\frac{1}{2}^{\circ}$  south, longitude  $103^{\circ}$  east, and  $3\frac{1}{2}^{\circ}$  north,  $67\frac{3}{4}^{\circ}$  east, respectively. The trend of the axis of the eastern half of the canal is about south  $75^{\circ}$  east and of the western half, north  $58^{\circ} 40'$  west. The free period of this body of water being reasonably close to a half lunar day for a binodal mode of os-

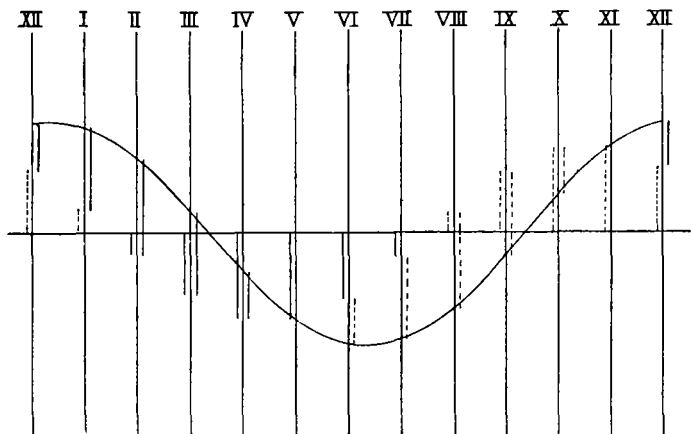


FIG. 2.

cillation, therefore the elongation of the particles, and the high or low water, must happen when the virtual work of the impressed periodic forces becomes zero.<sup>2</sup> For, as will appear from the inspection of fig. 2, the length and position of the

canal are such that the forces tend to incite a considerable oscillation; that is, their effects are not continually neutralized. At various assumed Greenwich lunar hours reduced to the local time by adding the east longitude, project the force arrows upon the axis of the canal.<sup>3</sup> Considering first the canal as uniform throughout its length, and supposing the forces to act upon equal masses undergoing equal but opposite displacements at the two nodes, the virtual work at any given time may be represented simply by the sum of the forces applied to the two nodes provided we regard those as positive which urge the water, say, toward the ends, and as negative those urging it from the ends toward the center. In fig. 2 the forces being applied only at the two nodes, are given equal weight; those acting on the western area are written to the left of the ordinate and those acting on the eastern are placed to the right. Forces directed westerly are represented by broken lines and easterly by full lines. The curve in fig. 2 may be regarded as representing the virtual work in the present instance for all hours because we can assume that at various times the magnitude of the arbitrary time element is so taken that at a given point the absolute length of the corresponding virtual displacement remains the same for all times; in other words, that the numerical values of the virtual displacements are independent of the time and depend only on the positions of the points considered. They are comparatively large at nodal lines and zero at the loops. Fig. 2 shows that high water at the ends should occur at III.36, Greenwich lunar time, and so at the middle at IX.36. Fig. 3 shows the surface of the water and the configuration of the forces at III.36 both for the nodal points and for points halfway between nodes and loops. It will be noted that the forces in the eastern half are then equal to those in the western and act in the same direction. But if the points are given a slight horizontal virtual displacement, as by putting them in positions which they occupy just previous to the time of elongation, it will be noted that for a uniform canal the displacements are equal and opposite in the two half-wave lengths. Hence, the sum of the products of the impressed periodic forces by the virtual displacements must be zero at the hour III.36.

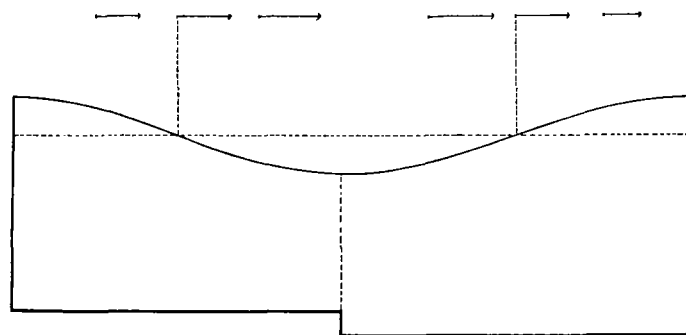


FIG. 3.—Scale of focus, 0.74 times that of fig. 2.

If two half-wave rectangular areas of different depths and widths meet end-to-end at a loop and are otherwise completely surrounded by rigid walls, the above rule for finding the time of tide by means of the virtual work can be carried out in almost as simple a manner as in the case where both are uniform; for, considering each area as being divided into the same number of elementary slices, the product mass  $\times$  force  $\times$  displacement in the two areas is proportional to depth  $\times$  width  $\times$  force. In other words, instead of giving equal weights to the two sets of values, as was done in fig. 2, one set is to be given greater weight than the other. Again, and this probably has more bearing upon the actual strip under consideration, it is reasonable to suppose that, because of the numerous straits eastward from Java, and the obliquity

<sup>2</sup> Appendix No. 7, United States Coast and Geodetic Survey Report for 1900, § 63.

<sup>3</sup> Ibid., §§ 2, 65.

of the northwestern coast of Australia to the general direction of the strip and the shoaling along this coast, a greater percentage of the forces acting upon the eastern half-wave area will be lost than of those acting upon the western. In other words, the set of values in fig. 2 belonging to the western part should have a slightly greater weight than the set belonging to the eastern. For this reason it appears that III is probably about as good a value for the times of high water of the stationary wave at the two ends as can be readily estimated from theoretical considerations.

Immediately connected with the whole-wave area is the Bay of Bengal. We can consider the water extending from the head of the bay to some distance southeast of Ceylon as a dependent area somewhat canal-like in form, with a nodal line extending from Ceylon to the western coast of Sumatra at a distance from the virtual head of the bay of  $\frac{1}{4}\lambda$ , or one-quarter of the wave length. This area synchronizes with the remainder of the system of which it forms a part, and the two together constitute the north Indian system.<sup>4</sup>

#### THE WATERS NORTH AND NORTHWEST OF AUSTRALIA.

The eastern half of the whole-wave area has, besides the stationary wave, whose high waters occur at III and IX, a progressive wave, due largely to straits or openings between the islands. Of special importance is the strait south of Timor Island. From this opening to the Gulf of Carpentaria, especially where the water is shallow, the tide is chiefly progressive, as shown by the cotidal lines. The progression due to this and other openings is felt half way or more to the African coast. On account of the great depth of the Banda Sea and of the shortness and considerable depths of the passages around Timor Island and vicinity, the tide is nearly simultaneous over this sea. It is somewhat later and a trifle smaller than the tide around Timor. The maximum eastward velocity through Ombay Passage north of Timor must occur between the time of mean sea level rising (for western Timor) and high water. The progressive wave due to this short strait, approaching from the west, must have its maximum velocity, or high-water phase, northwest of Timor at about the time of maximum velocity in the strait; consequently it must be in advance of what it would be were it to reach the Ombay Passage at the time of high water of the stationary wave. In other words, the tide just west or south of this boundary, pierced by short straits, is a little earlier than it would have been had the straits been broad and the area beyond shallow. It seems reasonable, therefore, to suppose that the progressive wave at the eastern extremity of the one-wave area (say about along the meridian of Kupang) should be about half an hour in advance of the stationary wave. Assuming that the amplitude of the progressive wave along the axis of the eastern part of the whole-wave area is equal to the amplitude of the stationary wave at the loops and that the former is half a lunar hour in advance of the latter at the loops, we have the distribution of the cotidal lines shown on the map along the central line of the area.

At first sight it seems strange that the amplitude of this progressive wave could be more than a small part of the amplitude of the stationary wave at the loops. But it should be noted that the energy coming through the tidal forces into the oscillating system is mainly consumed in overcoming the resistances experienced throughout its various parts. If now a part of this energy be lost to the system because of breaks in the boundary near a loop or because of extensive shoaling, the resulting progressive wave traversing a region small in comparison with the whole system may, for some considerable distance westward from the opening in the boundary, have an amplitude comparable with that of the remaining stationary

wave, and the system will oscillate nearly as it would in the case where no energy were thus lost; but, of course, the amplitude will be somewhat diminished.

It is reasonable to suppose that the southern extremities of the cotidal lines west of Australia and numbered IX to II turn eastward, somewhat as shown upon the map, because of the progression directed toward Timor Island.

#### THE HALF-WAVE AREA.

This area extends from Mozambique Channel to Baluchistan and India, being largely a dependent one whose tide is governed by the rise and fall in and just south of the channel. It has already been remarked that observation and theory give about 1.5 as the time of high water in the channel.

The bracketed values XII or 0 and VI, shown in fig. 1, are intended to refer only to the south Atlantic system; that is, they indicate the theoretical time of tide as it would be without the north and south Indian systems, and not the times of the actual tide.

Assume now the existence of the south Indian system without the north Indian; the tides in this area will, as was assumed before, synchronize with those in the channel, and so instead of 0 and VI we shall have about 1.5 and VII.5.

If, on the other hand, a wall were built across the channel, the theoretical times of tide produced in this half-wave area would then be II.1 and VIII.1.

Before considering the addition of the north Indian system, we shall lay down an important but quite general lemma, and which has also a bearing upon what has just been said.

If two areas or hypothetical systems overlap sufficiently or adjoin each other sufficiently far, they will generally reduce to one system because of synchronization, provided the free period of the resulting system (as ascertained by examining the dimensions of the resulting areas and noting the depths) has not been seriously altered or is equal to the assigned period. But if the free period of the resulting system has been considerably altered from that of the original systems, the two original

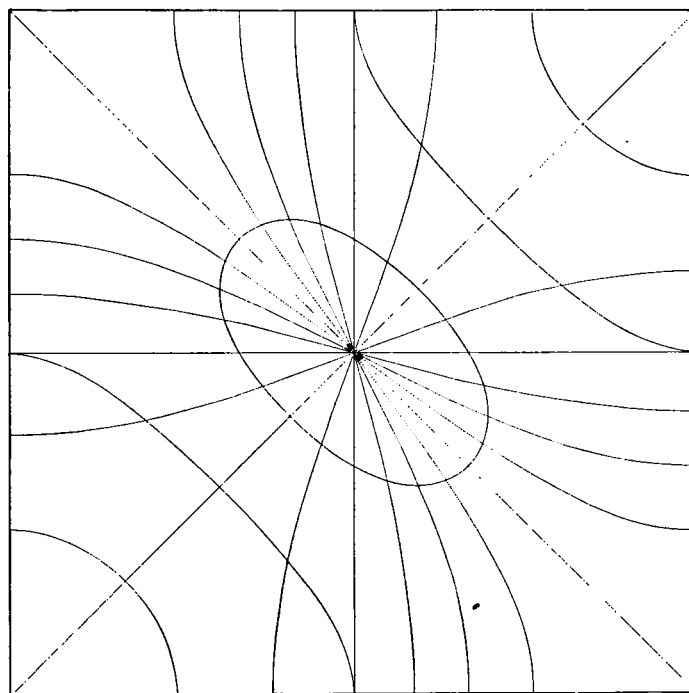


FIG. 4.

systems will not synchronize, but may oscillate nearly independently of each other. In a word, synchronization will not occur between two systems unless the constituent areas of the

<sup>4</sup>Cf. Appendix No. 7, United States Coast and Geodetic Survey Report, 1900, § 76.

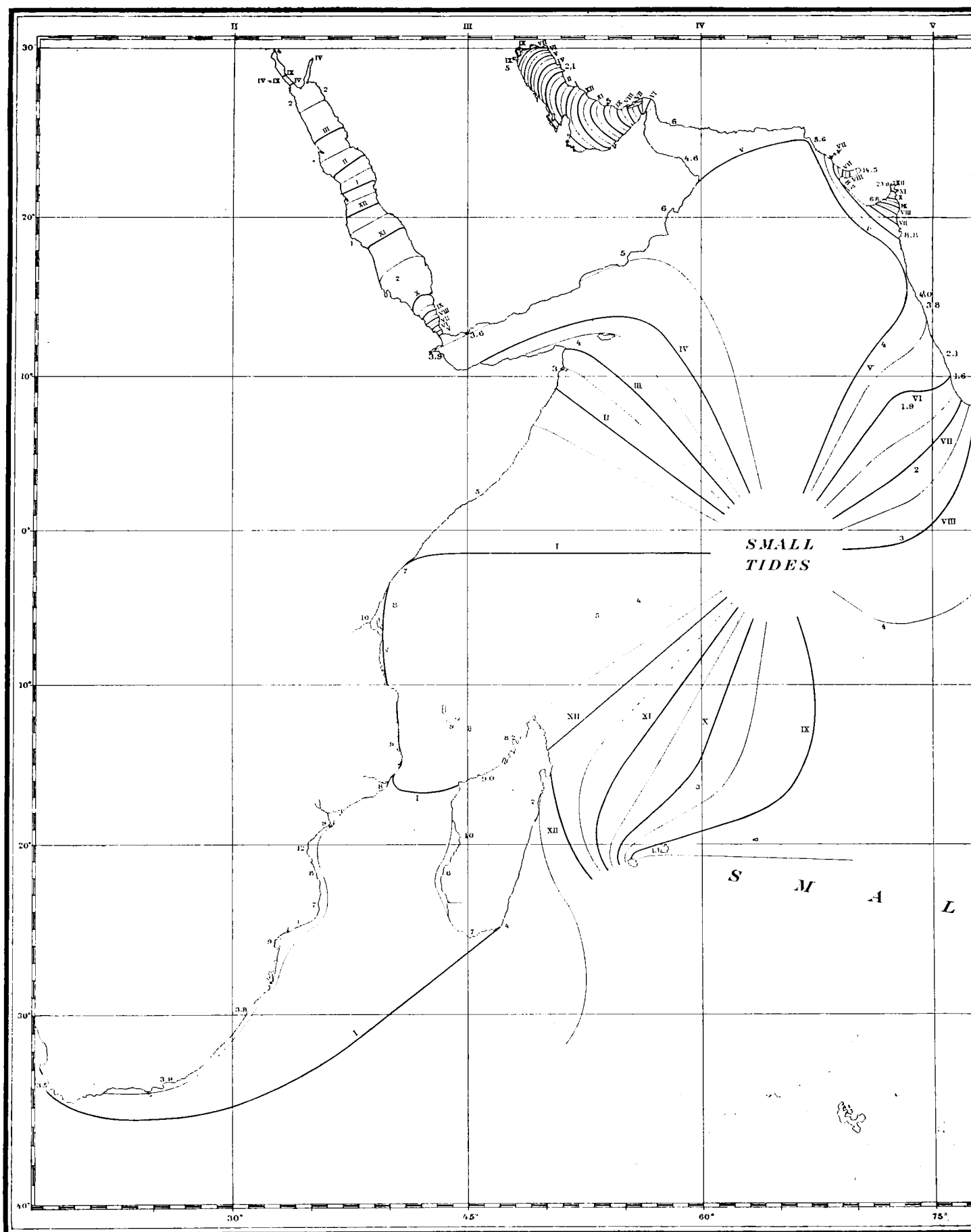
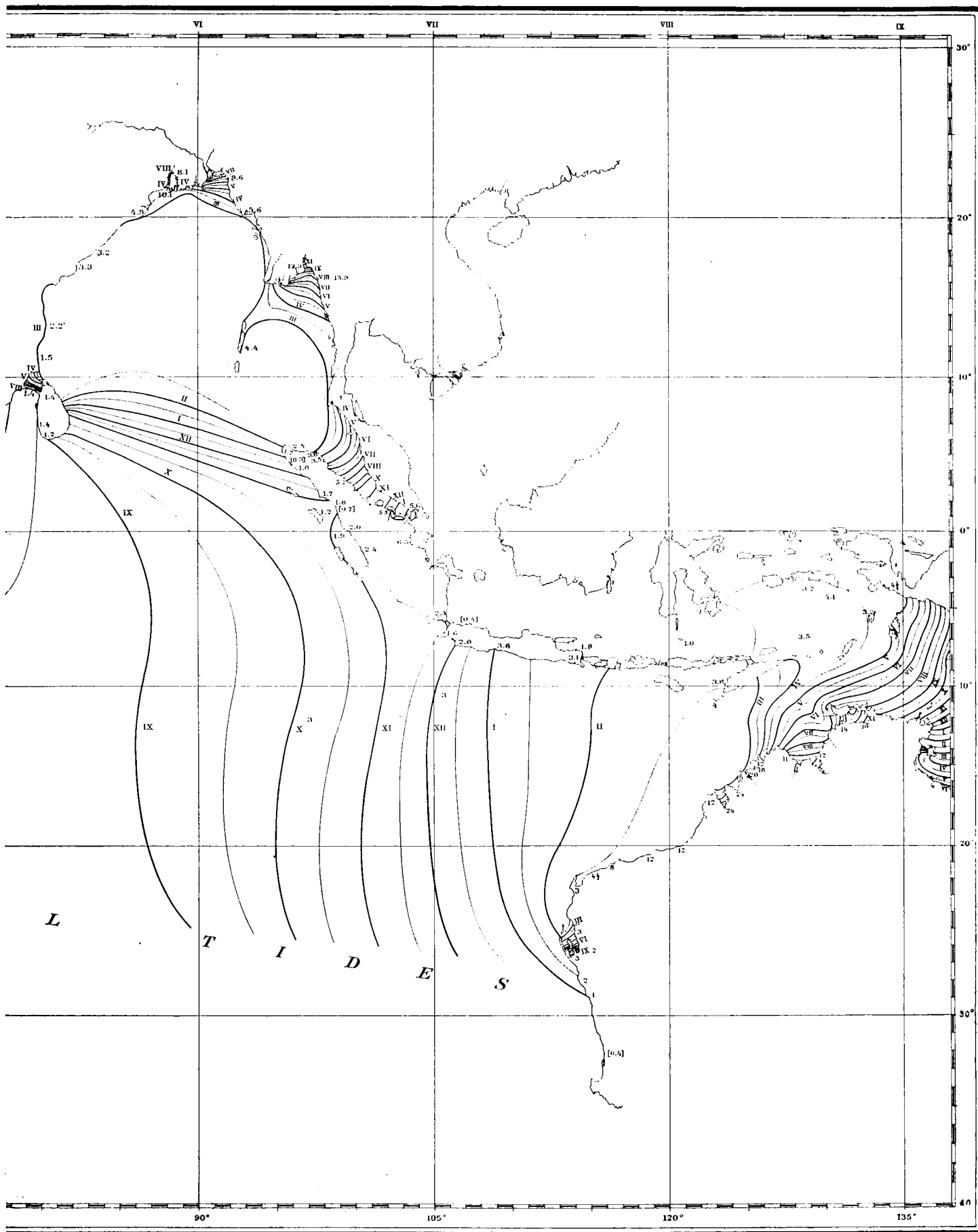


FIG. 5.—Cotidal lines for the



resulting systems have the given period as their own free period of oscillation.

Because of its symmetry, a square may form an exception to this rule; that is, there may be two independent oscillations at right angles to each other and differing in phase by any amount. There would then be two systems in one area.

But the L-shaped region extending from Mozambique Channel toward India, thence to northwestern Australia, can not have twelve hours as its free period because the virtual length of either of the two trapezoids into which the region can be divided is too small, being in each case less than that of the original rectangle. It is, therefore, fair to assume that the Mozambique-India half-wave area does not synchronize with the Australia-Arabia whole-wave area; for, although each has a free period approximating twelve hours, the period of the combination regarded as an L-shaped figure is much shorter.<sup>5</sup>

We can therefore suppose that the oscillations of the north Indian system and that of the Mozambique-India area are nearly independent of each other, although it is probable that the latter is accelerated a few minutes by the former because the loop in the Arabian Sea marked III, fig. 1, lies unequally with respect to the nodal line off Somaliland.

Before proceeding further, let us consider the case of two systems of oscillation in a square area. For simplicity, let the two amplitudes be taken as equal. Suppose the phase of the north-south oscillation to be  $60^\circ$  in advance of that of the east-west oscillation. Fig. 4 shows the arrangement of the resulting cotidal lines for each half hour, also the lines along which the range of the tide is constant. It is to be noted that the cotidal lines are crowded together near the nodal lines of the component oscillations. The crowding will differ from that shown in fig. 4, if we use another amplitude ratio and phase difference. But this figure will give a general idea of how the cotidal lines should be drawn for a square area. In all cases where the phase difference is not zero or  $180^\circ$  there must be a no-tide point around which the numbers of the cotidal lines progress, but not uniformly or at the rate due to depth. Where the phase difference is zero or  $180^\circ$  there will be a nodal line and no progression.<sup>6</sup>

Returning now to the Arabian Sea and adjacent waters we note that the conditions are far from having the simplicity of a square. Nevertheless, considering the superposition of two independent systems, it can hardly be doubted that there exists a point near the intersection of the nodal lines (fig. 1) where the range of tide is very small. It is almost certain that the cotidal lines should approximately radiate from this point being crowded together in the vicinity of Cape Guardafui and spread apart in the Arabian Sea and toward the Mozambique Channel. Moreover, the progression around this point should be clockwise and apparently irregular.

At the India end of the Mozambique-India region the east-and-west or whole-wave oscillation is probably as important as the north-and-south or half-wave: while at the south end the east-and-west oscillation is not directly felt. Hence, at India the tide occurs between the hours III and VII.5. In the Mozambique Channel, on the contrary, it occurs at I.5, or probably a little earlier (say at I), because of the slight influence of the north Indian system already referred to. Around the southern Maldiv Islands, and especially around the Chagos Archipelago, the half-wave oscillation does not exist. From the Arabian Sea to the loop south of Ceylon the tide is small, and there an irregular progression occurs, as is usually the case between two nonsimultaneous regions not too far apart.<sup>7</sup> There is also an irregular progression from the loop south of Ceylon to northern Madagascar. The direction of these progressions is clockwise, as was that inferred at the close of the preceding paragraph. In the gulfs of Aden and Oman the tide consists chiefly of stationary oscillations, although there

is some progression on account of the inner waters beyond. Each of these two gulfs constitutes a dependent canal-like area whose length is a small fraction of the wave length  $\lambda$ .<sup>8</sup>

The Persian Gulf being a large, shallow body of water connected with the Gulf of Oman by a large strait, has a tide which progresses at about the rate due to depth. There is some retardation and therefore some crowding up of the cotidal lines in the strait.

#### THE RED SEA.<sup>9</sup>

The tide in this sea is composed of a stationary wave caused by the tidal forces acting on its waters and a progressive wave produced by the outside tidal disturbances acting through the Strait of Bab el Mandeb. The force arrows applied to the nodal line of this sea regarded as a simple canal-like area whose period is about a half day, give IV.5 and X.5 as the cotidal hours of the north and south ends, respectively.

Because the range of the outside tide diminishes rapidly in passing through the strait, it is difficult to ascertain where a wave progressing at the rate due to depth will be established. But observations made at the north end of the sea indicate that high water of the resultant or combined wave occurs there at about III.75 hours, whereas according to what has just been said the high water of the stationary part should occur at IV.5. If now we assume the amplitude of the progressive wave over the Red Sea to be constantly equal to the amplitude of the stationary wave at the loops, and assume the phase of the progressive wave to be  $45^\circ$  in advance of the phase at the loops of the stationary wave, the result of combining the two is as shown by the cotidal lines, the extreme southern end of the sea being excepted. On account of the extreme narrowness of the strait, these assumptions concerning the progressive tide seem to be reasonable. In making the computations the depth of the sea was assumed to have a certain constant value over the region north of the nodal line and a slightly smaller but constant value over the region south of it. The manner in which the cotidal lines should be distributed in and near the strait is somewhat uncertain because the theory underlying such cases has not yet been worked out.<sup>10</sup>

As indicated by the map the tide in the narrow but deep Gulf of Akabah is chiefly a stationary wave, whose high water is about simultaneous with that at its mouth.

The tide in the much shallower Gulf of Tor is also chiefly a stationary wave with a node at Tor Bank.<sup>11</sup> However, as the ending of the gulf is not extremely abrupt there must be some small progression upward. Assuming the cotidal hour of both stationary and progressive waves to be III.75 at the mouth and the constant amplitude of the progressive wave to be one-eighth of the maximum amplitude of the stationary wave, we obtain the cotidal lines shown on the map.

NO LARGE WAVE PROGRESSES FROM THE SOUTH INDIAN OCEAN INTO THE NORTH INDIAN, PRODUCING THE TIDE OF THE LATTER.

An harmonic analysis of the tides at Freemantle, Swan River entrance, western Australia, shows that the average range of semidiurnal tide is there only 0.4 foot. A similar analysis at Port Louis, Mauritius Island, gives for the mean range of tide 1.1 feet. Again, the British Tide Tables give 3 feet as the spring range for the islands of Amsterdam and St. Paul, which is the same as the value there given for Port Louis and only a trifle greater than the value for Swan River. Hence, it is quite probable that the mean range of tide at these islands does not greatly exceed 1 foot.

Upon examining any chart of the Indian Ocean which shows the depths approximately, it will be seen, upon making a few measurements, that the region of small range extending from Freemantle to Mauritius Island can not indicate a true nodal line. Again, observations do not indicate that nearly the whole

<sup>5</sup> Cf. Ibid., § 42. <sup>6</sup> Cf. Ibid., §§ 26, 32. <sup>7</sup> Cf. Ibid., lemma 25, § 70.

<sup>8</sup> Cf. Ibid., lemma 12, § 70. <sup>9</sup> Cf. Ibid., § 82. <sup>10</sup> Cf. Ibid., § 113.

<sup>11</sup> Cf. Ibid., § 81.

of the Indian Ocean belongs to one system as such an extended nodal line would imply.

We are therefore led to believe that there is a region of small semidiurnal tides extending from Freemantle to Mauritius Island, and that the absence of a good tide is due to the fact that the distance between western Australia and Madagascar does not approximate to  $\lambda$  or to  $\frac{1}{2}\lambda$  as an east-and-west stationary wave would require. However, on account of the progressive waves in various parts of the North Indian Ocean, there may be a small wave progression northward across the region of small tides just referred to.

There is some inward progression from Rodriguez northwesterly toward the Farquhar Islands and Cape Amber, but it is to some extent mixed up with the stationary wave around northern Madagascar. That is, it is a somewhat irregular progression. In fact the tide between Rodriguez Island and Cape Amber is due chiefly to the rise and fall at the north end of Mozambique Channel. That is, a species of dependent oscillation, part stationary and part progressive, is maintained by this rise and fall. A somewhat similar effect may exist off Northwest Cape, Australia.

#### MISCELLANEOUS REMARKS.

Upon referring to fig. 1 it will be noticed that because of proximity to nodal lines the range of tide around Ceylon and southern Hindustan must be small. For the same reason the tide along the outer or southwestern coast of Sumatra should be small. The tide at the western end of the southern coast of Java should be smaller than is the tide farther east. All these requirements accord well with the observed facts as can be seen upon referring to the large map, fig. 5.

The distribution of the cotidal lines through each of the nodal lines respectively located east of Ceylon, off the Malabar coast and off Somaliland, has not been made, upon the map, in accordance with any assumed mathematical law. The lines are chiefly conjectural although in accord with the observations.

Upon measuring the dimensions of the oscillating areas, it may appear that the actual lengths are a trifle too short for the existence of large tides, although no definite criterion has been laid down in such matters. There are difficulties in the application of Lagrange's rule to even a canal-like body of variable depth. It seems, however, upon comparing the times required for the eruption of Krakatoa to have been felt at ports in India, Arabia, and Africa, that the areas as laid down on fig. 1 must have a free period sufficiently long to permit good stationary oscillations.<sup>13</sup>

The map shows several cases in which a derived wave is produced at a sudden shoaling.<sup>13</sup> For example, the Gulf of Martaban, the vicinity of the mouths of the Ganges, the Gulf of Cambay, and off the Gulf of Kutch. The progression north of Australia is due largely to such sudden shoalings as the Sahul Bank. A dependent stationary wave is apparent in the Gulf of Kutch, and some traces of dependent stationary waves, shown in the acceleration of the times of the tide, can be seen at the 80-mile beach (on the northwestern coast of Australia) and near and in the mouth of the Hugli River.

Sokotra Island and neighboring shoal have some influence upon the distribution of the cotidal lines in that locality. A similar remark may be made concerning the Laccadive and Maldivé islands.

In passing through Sunda Strait, the range rapidly diminishes, while the cotidal lines bunch up.<sup>14</sup> A somewhat similar statement is true of the narrow straits farther east.

The tide wave entering Palk Strait proceeds southwesterly

up Palk Bay, at about the rate due to depth, nearly to Adams Bridge.

The tide proceeds southeasterly through Malacca Strait, but not at the rate due to depth alone, excepting in the broader portion.

#### EVIDENCE OBTAINED FROM TIDAL STREAMS.

The directions of the observed tidal streams as given in the Admiralty Pilots afford some clue to the character of the tidal oscillation, especially in localities where the motion is rectilinear. Around the Maldivé Islands the flood stream sets easterly and around the Chagos Archipelago it sets southeasterly. In the northern end of Mozambique Channel the flood sets southerly and in the southern end northerly. Moreover, we find that flood slack occurs soon after high water in the channel, as a stationary oscillation requires. These facts could have been inferred from figs. 1 and 5.

On the southern coast of Cape Colony, from Table Bay eastward to Port Alfred, no sensible tidal stream exists although there is a moderately large rise and fall. This is in accordance with the lines of motion terminating at the shore which runs nearly perpendicular to them. See fig. 1.

The southern shore of Baluchistan lies at the loop of the half-wave area as also of the whole-wave area. Consequently the tidal streams should there be weak, and observation shows this to be the case.

Across the shoals and around the islands east and northeast of Madagascar, there are strong tidal streams. According to the map of cotidal lines, this is a region where the tide varies both in time and in range; such conditions always imply large accelerating forces for the water masses and generally large velocities, especially over shoals.

In the short straits which separate from one another the islands east of Java, the currents should be swift. This statement is confirmed by observation. But whether or not the time of maximum flood velocity is an hour or so before the time of high water at the southern ends of the straits has not yet been ascertained.

Strong tidal currents occur among the Nicobar Islands and generally among the Andaman Islands. At Table Island the streams turn at about the times of high and low water.

The streams in the Gulf of Suez accord well with the notion of a stationary wave, the times of slack water very nearly coinciding with the times of the tide at the head of the gulf.

#### THE ENDOWMENT OF RESEARCH IN METEOROLOGY.

[In the summer of 1902, the Chief of the Weather Bureau and other officials had occasion to present to the Carnegie Institution their views on the subject of the application of a portion of the funds of that institution to the promotion of research in meteorology. The ideas then presented were not very different from those lately defended in an interesting paper of a general character by Professor Chamberlin, the eminent geologist of the University of Chicago, who has himself published important papers bearing on the connection between the atmosphere and geology. In the belief that Professor Chamberlin's paper must contribute to promote research in meteorology and elevate the standing of our science in the colleges and universities of the country, we have requested him to present it for publication in the MONTHLY WEATHER REVIEW; in an early number we shall also submit the special reports presented to the Carnegie Institution.—ED.]

#### HOW CAN ENDOWMENTS MOST EFFECTIVELY AID RESEARCH?

By Prof. T. C. CHAMBERLIN, Head of the Department of Geology, University of Chicago.

I am not sure that I have rightly apprehended the special phase which it is desired the discussion should take, if, indeed, it is desired that it should take any one trend rather than another among those that are perhaps equally embraced under the broad theme announced. I have interpreted the above question as though it read, *By what assignment of endowments can research be most effectually aided?*

I assume that, with some rare exceptions, endowments may

<sup>13</sup> Cf. The Eruption of Krakatoa and Subsequent Phenomena, tabulation opposite page 148 and Plate XXXV.

<sup>14</sup> Cf. Appendix No. 7, United States Coast and Geodetic Survey Report, 1900, lemma 10, § 70.

<sup>15</sup> Ibid., §§ 104-106.